ASD TR 7-888 (VI)

ASD INTERIM REPORT 7-888 (VI)
October 1963

Development of ULTRASONIC WELDING EQUIPMENT for REFRACTORY METALS

53768

by
Nicholas Maropis

AEROPROJECTS INCORPORATED
West Chester, Pennsylvania

Contract: AF 33(600)-43026
ASD Project No. 7-888

Interim Technical Progress Report
July through September 1963

Design, development, and construction of the 25-kilowatt spot-type welding machine has continued, with emphasis on refining the design of the tension-shell ceramic transducer and coupling systems, analysis of the adequacy of the hydraulic system, and assembly of components onto the welding machine structure. Requirements for the 25-kilowatt motor alternator components and associated switching requirements were established, and procurement of these components is underway.

FABRICATION BRANCH
MANUFACTURING TECHNOLOGY LABORATORY

AFSC Aeronautical Systems Division
United States Air Force
Wright-Patterson Air Force Base, Ohio

NOTICES

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ABSTRACT-SUMMARY
Interim Technical Progress Report

ASD Interim Report 7-888(VI)
October 1963

DEVELOPMENT OF ULTRASONIC WELDING EQUIPMENT FOR REFRACTORY METALS

Nicholas Maropis
Aeroprojects Incorporated

Design, development, and construction of a 25-kilowatt spot-type welding machine has continued, with emphasis on refining the design of the tension-shell ceramic transducer and coupling systems, analysis of the adequacy of the hydraulic system, and assembly of components onto the welding machine structure. Requirements for the 25-kilowatt motor alternator components and associated switching requirements were established, and delivery of these components is expected about November 30, 1963.

Modifications are being made in the ceramic transducer design to eliminate arcing and overheating at high power inputs and to permit operation at full design power. The power-force programming system has been found to operate satisfactorily, with low response time, and components are being mounted on the welder frame. Final review of the air-hydraulic force system indicates that it should provide adequate force range, response time, and safety of operation. Installation and checkout of this system on the frame have been essentially complete.

FOREWORD

This Interim Technical Progress Report covers the work performed under Contract AF 33(600)-43026 from July 1, 1963 through September 30, 1963. It is published for technical information only and does not necessarily represent the recommendations, conclusions, or approval of the Air Force.

This contract with Aeroprojects Incorporated of West Chester, Pennsylvania, was initiated under ASD Manufacturing Technology Project 7-888, "Development of Ultrasonic Welding Equipment for Refractory Metals." It was administered under the direction of Fred Miller of the Fabrication Branch (ASRCTF), Manufacturing Technology Laboratory, AFSC Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

This project is under the direction of J. Byron Jones, with Nicholas Maropis serving as Project Engineer. Others associated with the program are Carmine F. DePrisco, Chief Electronics Engineer; John G. Thomas, Metallurgist; Janet Devine, Physicist; Jozef Koziarski, Ultrasonic Welding Laboratory Director; and W. C. Elmore, Consultant. This document has been given the Aeroprojects internal report number of RR-63-6, and is an interim report. Information reported herein is preliminary, and subject to further analysis and modification as the work progresses.

The methods used to demonstrate a process or technique on a laboratory scale are usually inadequate for use in production operations. The objective of the Air Force Manufacturing Methods Program is to develop, on a timely basis, manufacturing processes, techniques and equipment for use in economical production of USAF materials and components. The program encompasses the following technical areas:

Rolled Sheet	Powder
Forgings	Component Fabrication
Extrusions	Joining
Castings	Forming
Fiber	Material Removal
Fuels and Lubricants	Solid-State Devices
Ceramics and Graphites	Passive Devices
Nonmetallic Structural Materials	Thermionic Devices

Your comments are solicited on the potential utilization of the information contained herein as applied to your present or future production programs. Suggestions concerning additional Manufacturing Methods development required on this or other subjects will be appreciated. Direct any reply concerning the above matter to the attention of Mr. W. W. Dismuke, ASRKRA.

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PUBLICATION REVIEW

Approved by: J. Byron Jones
J. Byron Jones

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Phase II

INTRODUCTION

Since ultrasonic welding was first demonstrated as a practical method for joining thin gages of aluminum and other common metals and alloys, the equipment capability has been continuously extended to joining materials of increasing thickness as well as newer metals and alloys that are difficult or impossible to weld by other techniques. The aerospace need for high-temperature, corrosion-resistant, refractory metals and alloys has emphasized the need for ultrasonic welding machines of greater capability than are now available.

The objective of this program is to design, assemble, and evaluate heavy-duty ultrasonic welding equipment for joining refractory materials and superalloys in thicknesses up to 0.10 inch, and to develop necessary techniques for producing reliable welds in these materials. The accomplishment of this objective is divided into three phases: Phase I is concerned with establishing feasibility, defining problem areas, and delineating appropriate solutions thereto. Phase II embraces the development of the required equipment and techniques. Under Phase III, the performance characteristics of the ultrasonic welding equipment will be demonstrated.

Under Phase I, completed prior to the current reporting period (1)*, the feasibility of producing ultrasonic welds in both monometallic and bimetallic combinations of Cb(D-31), Mo-0.5Ti, Inconel X-750, PH15-7Mo stainless steel, René 41, and tungsten was demonstrated. By extrapolating the weldable gage capability of 4-kilowatt and 8-kilowatt ultrasonic spot-type welders, and utilizing a previously developed first-approximation criterion for the energy required to weld materials of various hardnesses and thicknesses, the electrical power input to the transducer necessary to join the above materials in gages up to 0.10 inch was estimated as approximately 25 kilowatts.

* Numbers in parentheses refer to List of References at end of report.

Also under Phase I, the problems involved in the production of heavy-duty ultrasonic welding equipment were delineated, a systematic approach to solving these problems was outlined, and requirements for the requisite heavy-duty spot-welding equipment were defined. The basic concepts involved in such machines were investigated. Spot-type welders for high-power operation were studied in considerable detail. Both theoretical and experimental information were evolved to support the design requirements for this type of machine.

A

A survey of the "state of the technology" of transducer materials and coupler materials, supplemented by laboratory investigations, indicated that the transducer-coupling system for the heavy-duty equipment should utilize lead-zirconate-titanate ceramic transducers, and aluminum-bronze, K Monel, or beryllium-copper coupling members. The requisite vibratory power can be delivered to the weld zone by means of an opposition-drive transducer-coupling system.

Ultrasonic welding of the refractory metals during the course of this program, and subsequent work involving refractory metals on concurrent programs have indicated the suitability of Astroloy and Udimet 700 alloys as tip materials.

Preliminary studies indicated that the transducer-coupling systems could be driven by either a motor-alternator or an electronic generator providing about 25 kilowatts of 15-kilocycle electrical power. If the motor-alternator were selected, solid-state elements would be considered to meet the switching requirements.

The work initiated under Phase II has the following objectives:

1. Develop the necessary methods, techniques, and equipment to ultrasonically join the selected materials.

2. Design and construct ultrasonic joining unit(s) in accordance with the approach outlined in Phase I.

3. Develop methods and techniques to demonstrate the capability of the equipment developed under Phase II to join the selected materials.

This report describes the work accomplished during the interval July 1, 1963 through September 30, 1963. Emphasis was placed on the development and fabrication of the primary equipment elements required in the 25-kilowatt ultrasonic spot-type welding equipment, including the determination of specifications for the tension-shell ceramic transducers and ultrasonic coupling systems, and assembly of the welding machine. The third item above, equipment capability studies, will be initiated after equipment assembly has been completed.

I. MATERIAL INVESTIGATIONS

"THE OBJECT OF PHASE II IS TO DEVELOP THE NECESSARY METHODS, TECHNIQUES, AND EQUIPMENT TO ULTRASONICALLY JOIN THE SELECTED MATERIALS."

Materials investigations requisite to fulfillment of Phase II were essentially completed prior to this report, and no further work in this area is anticipated until the 25-kilowatt welder is operating. The present status of these investigations is summarized briefly below.

WELDMENT MATERIALS

The necessity for using high-quality materials in the ultrasonic welding of high-temperature and refractory metals and alloys has been indicated throughout this program, as well as in other related programs. Suitable materials of known metallurgical history, although of indeterminate quality, have been obtained (2) for welding investigations with the 25-kilowatt welder. These materials include columbium D-31 alloy, Inconel X-750, molybdenum-0.5% titanium, PH 15-7 Mo stainless steel, René 41, and tungsten, all in the stress-relieved or annealed condition, in sheet gages up to 0.10 inch.

TIP MATERIALS AND GEOMETRY

As a consequence of extended experiments with welding-tip materials, both Astroloy and Udimet-700 have demonstrated good welding performance and long service life. These materials have similar chemical compositions, similar mechanical properties, and essentially identical metallurgical structures. Sufficient material is on hand for the fabrication of tips for the 25-kilowatt welding machine from both of these materials.

Investigations of welding tip geometry have established that tips having a spherical radii of 0.85, 1.75, 3.7, and 6.0 inches should effectively weld the entire range of sheet thicknesses from 0.005 to 0.10 inch.

II. EQUIPMENT DEVELOPMENT

"THE CONTRACTOR SHALL DESIGN AND CONSTRUCT AN ULTRASONIC JOINING UNIT IN ACCORDANCE WITH THE APPROACH OUTLINED IN PHASE I."

Work has continued on the critical components for the 25-kilowatt spot-type welding machine, including the transducer and coupler systems, the power-force programming system, and the air-hydraulic force system. Problem areas are being resolved and final construction and assembly are in process.

TRANSDUCER

TRANSDUCER DESIGN

It has previously been noted (3) that the tension-shell ceramic transducer design probably provides the most desirable characteristics for the transducer assembly in that the ceramic elements are entirely enclosed, thus eliminating hazardous, exposed high voltages, and permitting cooling channels within the components. In general, this design should provide a suitable system for application in production-type environments.

Prior tests (3) on early models of this tension-shell design for operation at intermediate power levels (2 kilowatts and 3.3 kilowatts), made by coupling the vibratory energy into an acoustic absorber, showed electromechanical conversion efficiencies of up to 92 percent. Each of these units, however, has operated successfully on a continuous basis at up to only about one-half of its design power. Continuous operation is of course not required of a spot-type welder. A duty cycle of about 0.50-1.0 seconds on, with about 2-4 seconds off, as needed for a spot-type welder, does greatly alleviate the transducer heating problem. With the 3.3-kilowatt unit, for example, continuous power was applied up to 1600 watts. At higher powers, arcing occurred across the ceramic elements or between the center metal washer and the shell.

The basic designs and the data obtained thereon were recently reviewed in detail with representatives of the Clevite Corporation, manufacturers of the lead-zirconate-titanate ceramic elements. In particular, the following design specifications were considered:

1. The driving field is limited to that associated with a dielectric loss (tan δ) of 4 percent.
2. Design power is based upon 3 watts/cm^3/kc.

3. Ceramic thickness is based upon the strain associated with a given design power.

Clevite personnel affirmed that conformance with these specifications should lead to very satisfactory operating characteristics, and further that this design represents at least as good as any they know to exist in the industry, including underwater sound designs of which only limited details are available. The power that has been applied to the 3.3-kilowatt unit and the resulting efficiency are said to be superior to any data reported by others using ceramic transducers at high power levels.

It was surmised that the difficulties in operating at higher powers than those noted above could be attributed to the heat-power limitations of the units. As the ceramic elements heat, the dielectric loss increases, and a serious feedback situation can exist. Consequently, more effective cooling is indicated. The intermittent duty cycle of course eases the cooling problem as stated previously.

The end sections of the transducer assembly probably provide an adequate heat sink for the ceramic elements, but the center metal washer may not. To be effective, the coolant would have to travel at relatively high velocity through the cooling channels of the center washer. Increasing the thickness of this washer will insure a more uniform temperature distribution on the faces.

The arcing that caused difficulties in early tests could not be explained on the basis of the dielectric strength of the ceramic or of its environment, since these units should be capable of up to 10,000 volts without arcing. Any arcing tendency should be minimized by rounding the corners of all surface boundaries in the vicinity of the driving field. It was noted that moisture should not be responsible for arcing, since lead-zirconate-titanate does not absorb moisture. Some moisture may adhere to the surfaces, but most of this should be removed by heating, and the small amount remaining would not contribute to conduction and therefore not lead to arcing.

It was pointed out that the arcing might occur as a consequence of a partial mechanical failure of a ceramic wafer, perhaps on a microscale. Such a failure could occur, for example, because of the differential thermal expansion between the ceramic and the metal during heating. In this connection, the Clevite personnel referred to data which they had recently developed (4) revealing an anomalous behavior of the PZT-type ceramic in its thermal expansion properties as a function of temperature. It was noted that the thermal expansion of these ceramics after being poled is anisotropic during subsequent heating. For example, the expansion coefficient in the direction perpendicular to the poling axis rises sharply from about $1.5 \times 10^{-6}/°C$ at room temperature to about 6.5×10^{-6} at 120°C, then slopes negatively to 4×10^{-6} at 275°C. This behavior can be altered markedly by heating the ceramic above the temperature at which it is to be used, and holding at that temperature for approximately one hour. For example, after heating PZT ceramic composition to 250°C, the expansion coefficient varied almost linearly from about 1×10^{-6}/°C at room temperature to 3×10^{-6} at 175°C.

On the basis of these data, the following recommendations were made:

1. The ceramic elements should be heat-cycled to a temperature above that at which they are to be used, so that operation will be out of the anomalous behavior region. It was recommended that our ceramic elements be heated to between 150° and 200°C and held at this temperature for about one hour. The furnace should be clean and the ceramic elements should be supported on zirconium plates.

2. The material of which the center metallic washer is fabricated should possess thermal expansion properties more closely matching those of the ceramic elements after heat cycling, as recommended in the referenced literature (4).

The design for the units projected for the 25-kilowatt machine was also reviewed, and it was concluded that this design should operate satisfactorily. It was suggested that the incorporation of four thicker ceramic wafers in the larger unit would serve to reduce the driving voltage and the matching coil requirements. This would also reduce the power density requirements to less than 3 watts/cc/kc and would partially relieve the heat problem.

The mechanical design details of the transducer assembly were also reviewed with Clevite Corporation personnel. Mechanical losses must be kept to a minimum, and we have provided for this. No slip can be tolerated between the ceramic and metal faces, since this would lead to mechanical losses and would aggravate the feedback situation. Losses even in the threaded joints of the assembly can lead to loss of efficiency.

The use of our acoustic calorimeter to provide a reproducible test load for transducer evaluation was considered a major contribution to transducer development.

As a result of this conference with Clevite personnel, it was concluded that the problems that have been encountered, as well as possible future problems in ceramic transducer design, fabrication, and test are basically thermal and mechanical rather than electrical. Any ceramic element failure for any of the above-noted reasons may be manifest in an electrical breakdown, but this could be the effect rather than the cause.

DESIGN MODIFICATIONS

Subsequent to the above review of the transducer assembly designs, the design for the high power units to be included in the 25-kilowatt welder was modified to provide a system that should be non-heat-power limited up to its design power capacity. The following changes were incorporated:

1. Four ceramic wafers instead of two for each transducer assembly.

2. Reduced power density per unit volume of ceramic.

3. Heat cycling of the ceramic wafers, as recommended, prior to assembly.

4. Three center washers, each washer projecting approximately 40 percent of its area beyond the ceramic element boundaries, thus augmenting heat transfer from the washer.

5. Greatly improved air cooling of the center washers.

6. Fabrication of the washers from Invar-36*, having a low thermal expansion coefficient, to reduce interfacial shear stress between the ceramic elements and the metal washers, thus minimizing the possibility of microcracks in the ceramics.

The 3.3-kilowatt transducer is being modified to incorporate these changes, and tests will be made to determine their effect before fabrication of the final high-power unit.

TRANSDUCER-COUPLING SYSTEMS

The previous report (3) described in detail the various types of transducer-coupling systems used in ultrasonic welding and noted the superiority of the lateral-drive system over the wedge-reed system, in that the former eliminates the necessity for vibratory mode conversion. The disadvantages of the standard lateral-drive system, particularly the moment developed in the coupler at high clamping forces and the tendency toward tip bounce, have been obviated by the independent development (5) of the overhung lateral-drive coupler system. Such a system, developed previously to permit making a single line-spot weld approximately 5 inches long, has performed satisfactorily at high power levels.

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* A nickel-iron alloy made by Carpenter Steel Company.

Figure 1 shows the geometry of an overhung-coupler system projected for use on the final 25-kilowatt welder. A transducer-coupling system incorporating this projected design and scaled to an intermediate power level has been fabricated and will be tested during the forthcoming period.

POWER-FORCE PROGRAMMING

Revisions in the power-force programming system installed on the 4-kilowatt welder have been completed and the system operates satisfactorily. Response time for both the force program and the power program elements is in the vicinity of 0.010 second, which is adequately low. Circuitry and controls have been checked out.

The only major change which might be required will involve the installation of a large servo valve to accommodate the higher oil flow volumes. Minneapolis-Honeywell, manufacturers of the force controlling elements, have agreed to provide such changes.

POWER SOURCE

All components for the 25-kilowatt motor alternator have been ordered in accordance with the requirements presented in the Appendix to this report. The major component parts for each are as follows:

1. Alternator
2. Variable-speed transmission
3. Primary drive motor

A check with manufacturers as to delivery schedules indicates that the above components can be delivered on schedule. However, a 2:1 speed reducer capable of handling high power is being manufactured by the Foote Brothers Corporation and is to be installed on the alternator. Apparently this speed reducer can not be delivered for installation until mid October, and this could delay final assembly and test of the power source.

In view of this schedule, a delay in the delivery of any critical component may delay delivery and final test of the complete unit.

HYDRAULIC FORCE SYSTEM

To ascertain the adequacy of the hydraulic system, including the hydraulic circuitry and force control components, for this large ultrasonic welder, an authority* on high-pressure systems was requested to make a

* Stulen Engineering Company, Caldwell, New Jersey.

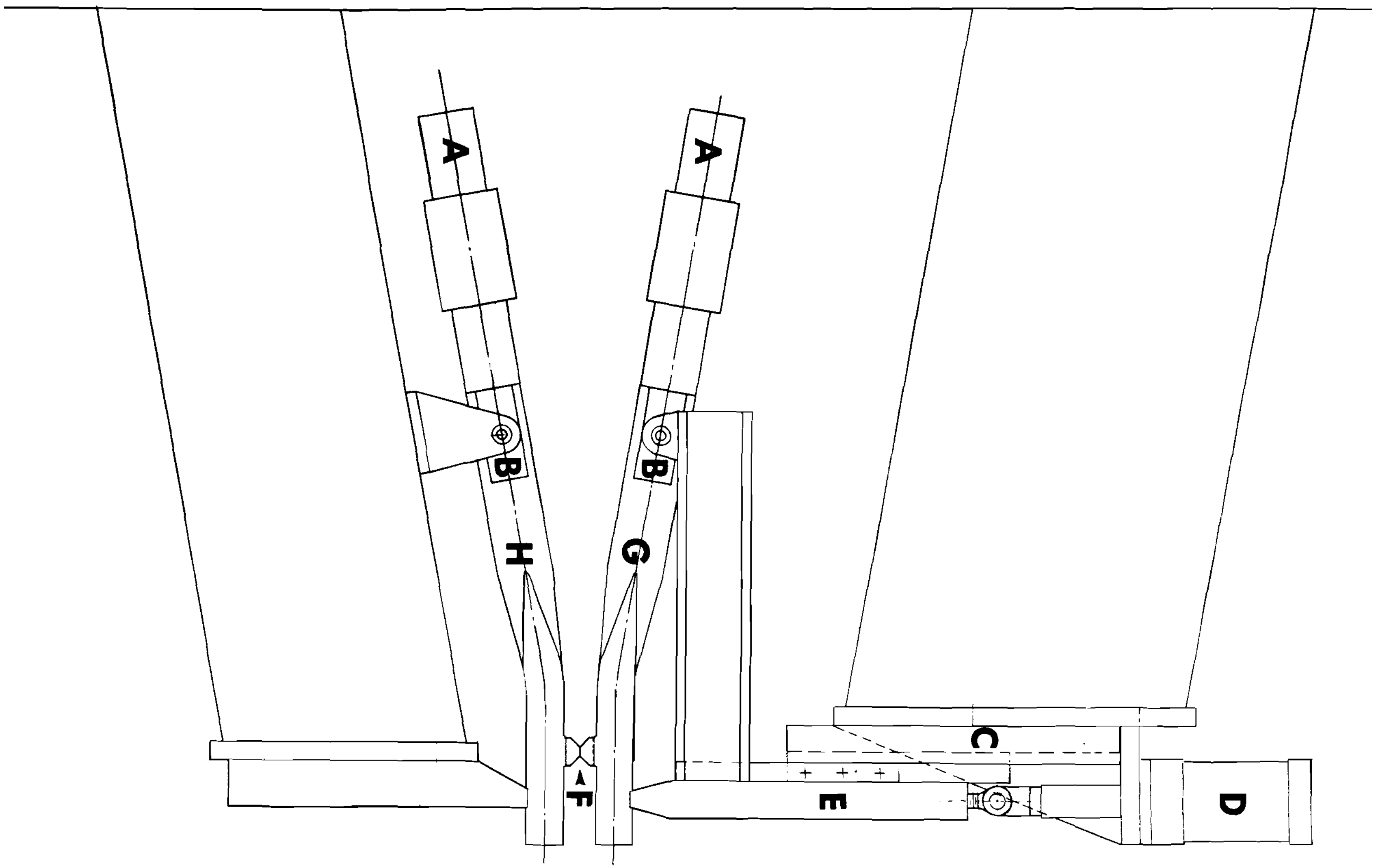

Figure 1

GEOMETRY OF THE OVERHUNG-COUPLER SYSTEM

A. Transducer Arrays
B. Force-Insensitive Supports
C. Front Support Way Slide
D. Force Cylinder
E. Force Rod
F. Sonotrode Tips
G. Upper Wave Guide
H. Lower Wave Guide

final review of the system. The review centered around itemized points. The comments on each follow:

1. Design operating range for the system: 250-5,000 pounds total force.

   With the components selected and with good control of the primary air pressure, the design specifications for the operating range will be met without difficulty.

2. Response of the force system to the control command signal.

   The response of the over-all system is difficult to predict. It has been established that response after the inital contact between the sonotrode and the work will be in the order of 0.010 second and will be limited only by the servo control circuit and valve. Emphasis was placed on the importance of keeping all high-pressure lines as short as possible and large enough so that flow is not restricted. These items have been provided for in the hydraulic circuit design.

3. Possible interaction between the air and hydraulic system resulting from the rapid variation associated with force programming.

   Air-hydraulic systems are used in many industrial operations and no difficulties have been reported of such interactions. The air supply provides the primary force, and the directly coupled hydraulic force provides the secondary force at higher force levels. The high response requirements of force programming should present no problem.

4. Adequacy of the system from the safety standpoint.

   Heavy-duty industrial components have been selected for the hydraulic system to insure adequate safety of the over-all system. There is no guarantee that an operator will not put his hand between the sonotrode and the workpiece, but design against such an occurrence is almost impossible.

As a result of this review, it was concluded that the force system selected for this machine should adequately serve the intended purpose.

MACHINE STRUCTURE

Work has continued with the installation of the hydraulic and control components on the heavy-duty welding machine framework. Figure 2 shows the current status of the assembly. The temporary plywood front panels (Figure 3 of Ref. 3), to which some of the components are attached, will be replaced

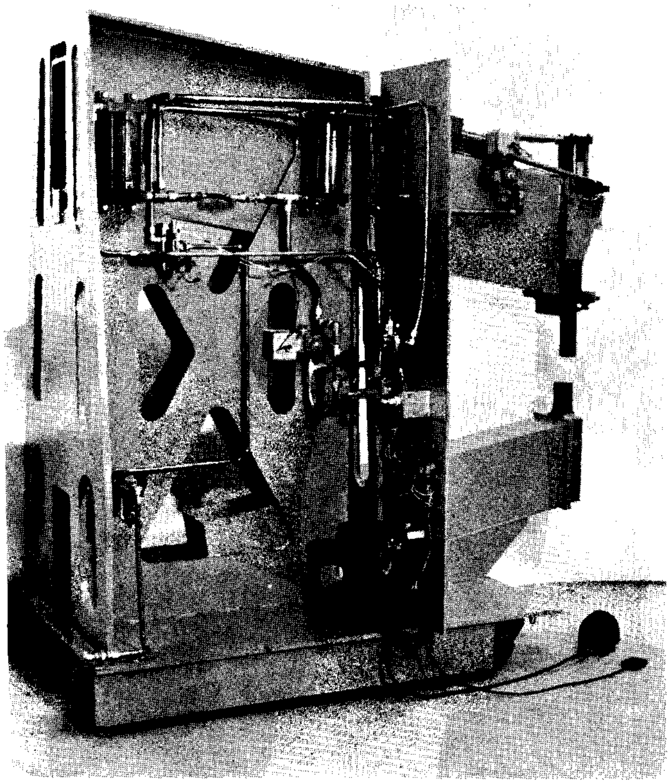

Figure 2

FRAMEWORK OF 25-KILOWATT SPOT-TYPE WELDING MACHINE with heavy-gage aluminum sheet. After all of the control components have been accurately located, the basic machine function components will be located on the left panel and the ultrasonic control and read-out components on the right panel.

All of the hydraulic components associated with the force system, with the exception of the servo valve, have been mounted on the frame. The system was tested and found to operate satisfactorily. Response times will be given a final check after the power-force programming control has been installed.

The wayslide for attachment to the front face of the upper extension beam, which will carry the ultrasonic system, has also been installed. As soon as the ultrasonic power control components have been mounted on the right panel, they will be tested in conjunction with a standard low-power ultrasonic welding system temporarily attached to the front of the machine.

LIST OF REFERENCES

1. Aeroprojects Incorporated, "Development of Ultrasonic Welding Equipment for Refractory Metals," ASD Interim Report 7-888 (II), Contract AF 33(600)-43026, December 1961.

2. Aeroprojects Incorporated, "Development of Ultrasonic Welding Equipment for Refractory Metals," ASD Interim Report 7-888 (IV), Contract AF 33(600)-43026, August 1962.

3. Aeroprojects Incorporated, "Development of Ultrasonic Welding Equipment for Refractory Metals," ASD Interim Report 7-888 (V), Contract AF 33(600)-43026, July 1963.

4. Cook, W. R., Jr., Court, D. Berlin, and Schalz, F. J., "Thermal Expansion and Pyro-Electricity in Lead Titanate Zirconate and Barium Titanate," J. Applied Physics, 31, No. 5, May 1963.

5. Jones, J. Byron, Nicholas Maropis and Florence R. Meyer, "Development of Ultrasonic Line-Spot Welding Phase II Final Report," Research Report No. 62-17, Purchase Order No. P-158611 for Alcoa, April 1962.

APPENDIX

REQUIREMENTS

POWER SOURCE FOR 25-KILOWATT ULTRASONIC SPOT-TYPE WELDER

Alternator

Power: 25 kw nominal
30 kw maximum

Power variable by varying field control voltage.

Single Phase Output at two levels: 100/125 volts RMS
or
200/250 volts RMS

Shaft Speed: 5560 rpm

Output Frequency at 5560 rpm: 15,000 cps

Alternator enclosure to provide for self cooling.

Driving Characteristics: $WR^2 = 161$ lb-ft^2 at the input shaft of the reduction gear box.

Running horsepower: 65

VARIABLE-SPEED TRANSMISSION

1 H-5 modified P.I.V. and control levers properly connected to appropriate differential shafting

1 Set of coupling media to connect H-5 P.I.V. to differential transmission.

Output Speed: 2780 rpm $\pm$ 3-1/2%

Output Load: Running 65 hp

Output Inertia: 161 $lb\text{-}ft^2$

Weight: 1900 lbs.

PRIMARY DRIVE MOTOR

Synduction Type: 100 hp

Full Load Current: 200 amps wired for 440 volts

Locked Rotor Current: 1750 amps

Over-all Weight: 1280 lbs

Shaft Speed: 1800 rpm

DISTRIBU[illegible]ST

1 Acoustica Associates, Inc.
Attn: R. J. Hurley, General Manager
10400 Aviation Boulevard
Los Angeles 45, California

2 Aerojet-General Corp.
Attn: Kenneth F. Mundt, Vice Pres. Mfg.
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1 Aeronca Mfg. Corp.
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1 AiResearch Manufacturing Co.
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1 American Machine & Foundry Co.
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1 Armour Research Foundation
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1 [illegible] Aero[illegible]ystems Company
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1 Cessna Aircraft Corporation
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1 Fairchild Aircraft & Missile Div.
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1 General Electric Company
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1 General Motors Corp.
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1 Gulton Industries, Inc.
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2 Lockheed Aircraft Corp.
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1 Lockheed Aircraft Corp.
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1 Marquardt Aircraft Co.
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P. O. Box 179
Baltimore 3, Maryland

1 Martin Marietta Corp.
Attn: J. D. Best, Mgr.
Mfg. Res. Div.
Box 179, Mail #P30
Denver 1, Colorado

1 The Martin Company
Attn: L. J. Lippy, Dir. Fab. Div.
Denver, Colorado

1 North American Aviation, Inc.
Attn: Chief Engineer
Port Columbus Airport
Columbus 16, Ohio

1 North American Aviation, Inc.
Attn: Latham Pollock, Gen. Supv.
Mfg. Eng.
International Airport
Los Angeles 45, California

1 Northrop Aircraft, Inc.
Attn: R. R. Nolan, Vice Pres. Mfg.
1001 E. Broadway
Hawthorne, California

1 Northrop Aircraft, Inc.
Norair Division
Attn: Ludwig Roth, Dir. Research
Engineering Department
1001 E. Broadway
Hawthorne, California

1 Republic Aviation Corp.
Attn: Adolph Kastekowits, Chief Mfg.
Engr.
Farmingdale, Long Island, New York

1 Pratt & Whitney Aircraft Div.
United Aircraft Corporation
Attn: L. M. Raring
Chief, Metallurgical & Chemical Lab.
P. O. Box 611
Middletown, Conn.

2 Commanding General
Redstone Arsenal
Rocket & Guided Missile Agency
Attn: Chief, Space Flight Structure
Design
Redstone Arsenal, Alabama

1 Rocketdyne Division
North American Aviation, Inc.
Attn: R. J. Thompson, Jr.,
Director Research
6630 Canoga Avenue
Canoga Park, Calif.

1 Rocketdyne Division
North American Aviation, Inc.
Attn: Mr. J. P. McNamara, Plant Mgr.
P. O. Box 511
Neosho, Missouri

1 Rohr Aircraft Corporation
Attn: Chief Structures Engr.
P. O. Box 878
Chula Vista, Calif.

1 Rohr Aircraft Corporation
Attn: Burt F. Raynes, Vice Pres. Mfg.
P. O. Box 878
Chula Vista, Calif.

1 Ryan Aeronautical Company
Attn: Robert L. Clark, Mfg. Works Mgr.
Lindbergh Field
San Diego, California

1 Sciaky Bros., Inc.
4915 W. 57th Street
Chicago 38, Illinois

10 Armed Services Technical Info. Agency
Attn: Document Service Center (TICSCP)
Arlington Hall Station
Arlington 12, Virginia

6 & 1 repro Aeronautical Systems Division
Attn: Mfg. Technology Lab (ASRCT)
Wright-Patterson Air Force Base, Ohio

1 Air Force Systems Command
Attn: Mr. C. W. Kniffin (RDRAE-F)
Andrews Air Force Base, Maryland

1 Aeronautical Systems Division
Attn: ASRKCB
Wright-Patterson Air Force Base, Ohio

2 Aeronautical Systems Division
Attn: Metals & Ceramics Lab (ASRCM)
Wright-Patterson Air Force Base, Ohio

1 Aeronautical Systems Division
Attn: Applications Lab
(ASRCE, Mr. Teres)
Wright-Patterson Air Force Base, Ohio

2 Aeronautical Systems Division
Attn: Flight Dynamics Lab
Structures Branch (ASRMDS)
Wright-Patterson Air Force Base, Ohio

1 Battelle Memorial Institute
Defense Metals Information
Attn: Mr. C. S. Dumont
505 King Ave.
Columbus, Ohio

1 Ballistic Missile Systems Division
Attn: Industrial Resources
P. O. Box 262
AF Unit Post Office
Inglewood, Calif.

1 Chief, Bureau of Naval Weapons (PID-2)
Department of the Navy
Washington 25, D. C.

1 Frankford Arsenal
Research Institute 1010 (110-1)
Attn: Mr. E. R. Rechel, Deputy Director
Philadelphia 37, Pa.

1 Solar Aircraft Company
Attn: Engineering Library
2200 Pacific Highway
San Diego, California

1 Temco Aircraft Corp.
Attn: D. T. Brooks, Mfg. Mgr.
P. O. Box 6191
Dallas, Texas

1 Southwest Research Institute
Attn: Glenn Damewood, Dir. Applied Physics Dept.
8500 Culebra Road
San Antonio 6, Texas

1 Union Ultra-sonics Corporation
Attn: John Zotos, Chief Project Scientist
111 Penn Street
Quincy 69, Massachusetts

1 Vought Aeronautics Division
Chance-Vought Aircraft, Inc.
Attn: George Gasper, Mfg. Engr. Mgr.
P. O. Box 5909
Dallas, Texas

1 Vought Aeronautics Division
Chance-Vought Aircraft, Inc.
Attn: Chief Librarian, Eng. Library
Dallas, Texas

1 Vought Aeronautics Division
Chance-Vought Aircraft, Inc.
Attn: J. A. Millsap, Chief Engr.
Manufacturing Research Dev.
P. O. Box 5907
Dallas, Texas

1 G. C. Marshall Space Flight Center
National Aeronautics & Space Administration
Attn: William A. Wilson
Chief, MR & D Branch
Huntsville, Alabama

2 Langley Research Center
National Aeronautics & Space Administrative
Attn: Technical Director
Langley, Virginia